

BLIGHT, caused by the cucumber mosaic virus, is the most widespread and serious virus disease of spinach. The virus is transmitted from a number of wild and cultivated hosts to spinach by aphids, and the disease is most severe on fall and winter crops because of a greater build-up of inoculum in other hosts.

Symptoms of the disease appear as a general yellowing. Plants ultimately become completely yellowed, twisted, and stunted. If warm temperatures prevail, death of the plants quickly follows, but if air temperatures are cool, death does not occur for several days.

Virginia Savoy, a resistant variety, was developed in 1920. It is a hybrid of Bloomsdale Savoy and an Asiatic variety. Old Dominion, a second resistant variety, was developed by selection following a cross of Virginia Savoy and King of Denmark. This was one of the first successful attempts to control plant virus diseases by breeding resistant varieties. Virginia Savoy and Old Dominion are both savoy varieties and have been widely used for fresh-market spinach.

The resistance of Virginia Savoy is due to a single dominant gene that is dependent on certain air temperatures for expression of resistance. At temperatures below 80° F. resistant plants show no symptoms when inoculated, but at temperatures above 80° F. inoculated plants rapidly succumb with a systemic necrosis. Thus, in breeding programs the control of air temperature is of prime importance.

J. P. Fulton of Arkansas has isolated a strain of the virus from spinach to which Virginia Savoy and Old Dominion are readily susceptible.

GLENN S. POUND *has specialized in the diseases of vegetable crops since 1943.*

*J. P. Fulton: Studies on Strains of Cucumber Virus 1 From Spinach, Phytopathology, volume 40, pages 729-736, 1950.*

*M. C. Richards: Downy Mildew of Spinach and Its Control, New York (Cornell) Agricultural Experiment Station Bulletin 718, 1939.*

## Diseases of the Common Mushroom

*Edmund B. Lambert, Theodore T. Ayers*

The mushroom industry in the United States has developed around one type of mushroom—the common commercial mushrooms that are sold in the markets of all our large cities and are grown in caves or special sheds in which temperature and humidity can easily be controlled. Near almost every large northern city are several mushroom houses.

The industry is only about 50 years old in the United States, but it has developed rapidly to a production of about 60 million pounds of mushrooms a year.

Progress in the development of the techniques of growing mushrooms and the expansion of the industry have been due in large degree to progress in the recognition and control of diseases and insect pests. Before 1920 growers were never sure when an individual crop would be a total failure. Average yields were less than three-fourths of a pound to the square foot. The average yield now is about twice that. Cooperative work of the technical staffs of the spawn makers and the plant pathologists of the Pennsylvania Agricultural Experiment Station and the Department of Agriculture has made that possible. Further progress is in sight: Rather consistent yields of about 5 pounds the square foot have been obtained in small-scale experimental culture at Beltsville, Md.

Strangely enough, both the mushroom itself and many of the organisms

of the diseases that attack it are fungi.

The fleshy part of the mushroom that spreads out above the stem is known as the cap. Its function in nature is to produce and disperse the spores, the reproductive bodies. Each mushroom is nourished from the soil and compost beneath it by a system of threadlike moldy growth, which can be compared to the roots of the higher plants. But unlike the higher plants, the "root system" develops extensively before the mushroom appears above ground. The mushroom plant has no chlorophyll with which to manufacture its own carbohydrates from water and the carbon dioxide of the air. Therefore the mushroom "roots" must seek and assimilate organic nutrients in partly decomposed organic matter derived from plants and products of other organisms.

THE FIRST STEP in cultivating mushrooms is the collection and germination of spores. That is done under controlled laboratory conditions. The finished propagative material—the spawn—is a pure culture of threadlike growth in a solid medium. It is produced and sold in large amounts by specialists; the average mushroom grower need not be trained in the techniques of making spawn.

The grower's first step is to prepare a compost. For years horse manure has been used, but artificial composts of straw or old hay, fortified with corn-cobs, organic nitrogen, phosphates, and potash, have been gaining favor. Large heaps of the materials are moistened and mixed at weekly intervals to maintain a warm, moist, aerated, well-mixed pile. The object is to use up the food materials that might serve as food to the common airborne molds and leave a material in which the mushroom "root system" can better compete with the molds for nutrients.

After the heap has attained a proper degree of decomposition, the compost is adjusted to a favorable moisture content and placed in mushroom

houses on shelf beds about 6 inches deep. There are usually several tiers 5 to 6 beds high in a mushroom house, which can hold 50 tons of compost when filled. The compost continues to develop a warm fermentation in the beds. The grower closes the doors and all openings of the house so that, with the aid of supplementary heat, he can raise the inside temperature to 130° or 140° F. That temperature is maintained for about a week. The process is known as a "sweating out" or pasteurizing period.

The temperature then is lowered to about 65° or 70°, and spawn is placed in the bed. The spawn is allowed to grow undisturbed for about 3 weeks. By then it has spread as a threadlike growth through two-thirds of the compost in the beds, and the grower places a 1-inch layer of soil, a process called casing, over the surface of the bed. The spawn continues to grow in the beds and into the casing soil to form a coarser rootlike growth, which produces the mushrooms on the surface of the soil and serves to translocate the food to them from the compost.

The first mushrooms appear about 4 weeks after the beds have been covered with the soil. As growth proceeds, new mushrooms appear above the soil in a succession of waves of rapid growth and large numbers called flushes. Under good conditions the flushes occur every 4 or 5 days for 2 to 4 months, depending on the temperature in the growing houses. During the cropping period the grower waters the soil and maintains a temperature of 50° to 65°. At its end the nutrients in the compost are depleted and the beds are emptied.

The major causes of mushroom disorders, besides fungi, are nutrient deficiencies, toxic chemicals, bacteria, and nematodes.

We know of no disease of mushrooms that is caused by a virus, although the symptoms of one, the mummy disease, suggest that it may be caused by a virus.

Under certain conditions, some un-

desirable fungi competing for food in the beds will crowd out the growth of the planted spawn. Such undesirable fungi are called weed molds and are considered disease-producing agents. Traces of gaseous impurities in the air also produce abnormalities in mushrooms.

Years ago beds were "spawned" or inoculated by merely transferring pieces of grayish mushroom mold from an old bed to a new one. Later the mold growth was pressed into bricks, which were broken up and used for planting beds. Both methods failed to exclude diseases and insects from the spawn and from the new beds. To reduce contamination of the spawn, growers attempted to select wild spawn from the fields for use in the beds, but that was only trading trouble, for now they were unable to control the varieties grown or maintain favorable strains.

A half century ago, methods of germinating spores of known parentage under control, discovered in France and in the United States, made possible the production of disease-free spawn on a large scale—no longer could growers blame their troubles on poor spawn; they had to look to their methods of culture.

A powdery mold—the white plaster mold—appeared in the mushroom beds of many growers in the early days. It frequently crowded out the mushroom spawn. Growers noticed that this weed mold was usually associated with a wet, greasy condition and with traces of ammonia odor in the compost. This weed mold is seldom encountered now in mushroom houses. French growers were the first to add gypsum during the composting to control white plaster mold. An English scientist gave the explanation of the way in which gypsum acted. He showed that the white plaster mold was usually associated with a dispersion of the colloidal material in the compost resulting from an excess of ionized potassium and that the addition of gypsum (calcium sulfate) to the

compost served to flocculate these colloids.

Growers in the United States about 1920 began to allow their beds to sweat out immediately after filling them. The process drove insects to the surface of the beds, where they could be killed by fumigation. But frequently the process caused the beds to fill with an olive mold, which reduced yields and often caused complete crop failures. Control of this weed mold was accomplished by a refinement in the pasteurizing process.

It was shown about 1930 that the olive mold rarely appeared unless the temperature in the beds had gone above 150° F. during the last days of pasteurizing. Most growers therefore maintain their bed temperatures below 145° during pasteurizing. Recently it has been shown that if the temperature goes above 150°, the compost can be reconditioned by subsequently holding it for a few days below 140°. The explanation is that certain nutrients, presumably proteins, that cannot be assimilated by the olive mold are partly broken down by temperatures above 150° and thus made available to it. Under those conditions the mushroom spawn cannot successfully compete with the olive mold for food and is crowded out.

The reconditioning of the compost by holding it at 140° or below for a few days is accomplished by the conversion, by the microbial flora of the compost, of the available nitrogen into microbial protein, which is again unavailable to the olive mold but readily assimilated by mushroom spawn. All commercial growers in the United States now pasteurize their compost and rarely suffer losses from the olive mold.

Another puzzling problem that growers used to encounter was that some soils gave satisfactory yields when they were used to case the beds but other soils gave very poor yields. The reason was found to lie in the intolerance of mushroom spawn to acid soil. Most of these unsuitable

soils can be made into good casing soils by bringing their reaction to between pH 7.0 and pH 7.7. Care is needed, though: Some limestone is toxic to spawn because it contains too much magnesium.

Casing soil often harbors the causal organisms of bubbles, brown spot, and mat diseases and parasitic nematodes, which can cause crop failure. Soils in many localities are free from harmful organisms, but if only contaminated soil is available it can be freed of disease organisms by treatment with chemicals or by steaming. In areas where mushrooms have been cultivated for many years nearly all growers fumigate or steam the soil.

Truffle disease, another weed mold, appeared in mushroom beds of a few growers about 1927. Soon many houses in this country and England, Australia, and South Africa had it. It cut the crops in half. It was suspected at first that the appearance of the mold was associated with high temperatures during the growing period but that idea was dropped when experiments showed that a pure culture of the truffle fungus grew well at 50° to 70° F., temperatures that are suitable for the growth of the mushroom spawn, and that the truffle fungus could withstand a temperature of 180°. In 1944 the mystery was solved: The fungus can grow vegetatively and produces fruiting bodies at temperatures below 60°, but its spores do not germinate below 60°. It became apparent that the widespread appearance of the disease was associated with a new practice, beginning about 1926, of growing the spawn in the beds at temperatures between 70° and 80°. Spawn now is grown below 70°, or below 60° if the disease has been prevalent in a grower's house. As the mushroom crop itself is always grown below 65°, the spores of the truffle fungus do not germinate. They are held in a dormant condition by the low temperature and can do no harm even though they are present in the beds.

During the cropping period, growers dust their beds with zineb, which con-

trols the verticillium spot disease and reduces late outbreaks of the bubbles disease. The lack of injury or reduction in yields when this fungicide is dusted on mushrooms in different stages of growth for the control of fungus diseases is remarkable since the host plant itself is a fungus—especially in view of the fact that the growth of spawn is sharply arrested when zineb is added to the compost or mixed with the casing soil.

Mushroom growers ventilate their houses as much as possible without excessively drying out the layer of soil on the surface of the compost. This practice is based on an obvious depression of growth or "sulking" of the mushrooms and reduced yields when mushroom houses are closed up for several hours. Experiments indicate that two gases given off by the growing mushrooms themselves, carbon dioxide and an unsaturated hydrocarbon gas, can cause toxic effects in tight houses.

Even when the crop is finished and the houses are empty, growers must take precautions against diseases. They heat the houses to 135° and introduce formaldehyde fumes to combat several diseases that otherwise could be carried over from one crop to another.

NEMATODES are a serious problem wherever mushrooms are grown commercially. They are hard to control and cause heavy losses. They may be actually parasitic on the hyphae or "rootlet system" of the mushroom. With other organisms, they may produce toxic substances. Probably they act as disease carriers.

Although nematodes were present in enormous numbers in mushroom compost, they were not known to be parasitic on mushrooms until 1949. For many years, the reduction in yields in some beds after two or three "breaks" and the total lack of production of mushrooms in others could not be satisfactorily explained. The cause of the trouble was believed to be due to a fungus always present on the affected beds until it was pointed out that the

fungus is not parasitic on the mushroom hyphae but acts as a predator on nematodes, which are the prime causes of the disease. Subsequent study showed that an undescribed nematode is parasitic on the mushroom hyphae and is responsible for the decreases in yields or the disappearance of the mushroom fungus from the compost.

The nematode has a stylet, or spear, with which it makes punctures in the hyphae. The punctures are avenues of entrance for bacteria, which otherwise would be unable to enter the hyphae. E. J. Cairns and C. A. Thomas in 1950 reported that the failure of many beds in the Kennett Square area of Pennsylvania was due to the activity of nematodes and bacteria in the compost. They believe that the tremendous numbers of both organisms produce metabolic products that inhibit the production of mushrooms but do not visibly injure the hyphae.

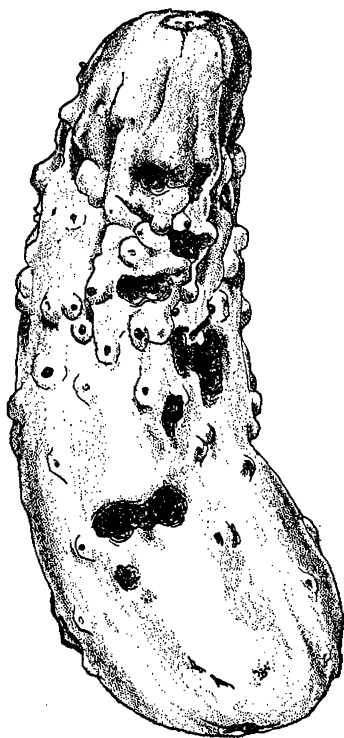
Most of the nematodes involved in the complex are free-living, nonstylet forms. The only known way to control the nematodes is to raise the temperature of the compost to at least 140° F. for several hours during pasteurization. The casing soil also should be heat-treated for several hours to eliminate the nematodes in it and prevent their introduction into the mushroom beds.

Nematodes were reported earlier to aid in the dissemination of bacteria responsible for injury to mushroom caps. A free-living and nonparasitic species is believed to be a carrier and distributor of the bacterium *Pseudomonas tolaasii*, the causal organism of the "blotch" disease of mushroom caps. The nematode also is suspected of disseminating other bacterial diseases of mushrooms. There are no means of controlling it after it has become established in the beds. More ventilation is recommended to lower the moisture on the mushroom caps so that the nematode will not be able to move about so freely and disseminate the bacteria causing the "blotch" and other diseases. It can be eliminated if the temperature of the compost is held

at 140° or more for several hours during the pasteurization process. The casing soil must also be treated similarly to prevent contamination of the compost with the nematode.

EDMUND B. LAMBERT, *senior mycologist in the Bureau of Plant Industry, Soils, and Agricultural Engineering*, received his doctor's degree in plant pathology at the University of Minnesota in 1926. He has been in charge of the Bureau's research on the diseases and cultivation of mushrooms since 1928. He represented the Department at an international conference on the scientific aspects of mushroom culture in England in 1949.

THEODORE T. AYERS, *a graduate of the Pennsylvania State College and Harvard University*, is associate plant pathologist in the division of vegetable crops and diseases of the Bureau of Plant Industry, Soils, and Agricultural Engineering.



Cucumber scab.